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Civil Aviation Research and Development

An Assessment of Federal Government Involvement

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AIR TRAFFIC CONTROL

A report by the ASEB Ad Hoc Committee
Air Traffic Control

AERONAUTICS AND SPACE ENGINEERING BOARD
NATIONAL ACADEMY OF ENGINEERING

CIVIL AVIATION RESEARCH AND DEVELOPMENT

An Assessment of Federal Government Involvement

AIR TRAFFIC CONTROL

AERONAUTICS AND SPACE ENGINEERING BOARD
NATIONAL ACADEMY OF ENGINEERING
Washington, D.C.
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The National Academy of Engineering was established in December 1964. The Academy is independent and autonomous in its organization and election of members, and shares in the responsibility given the National Academy of Sciences under its congressional act of incorporation to advise the federal government, upon request, in all areas of science and engineering.

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1. To provide means of assessing the constantly changing needs of the nation and the technical resources that can and should be applied to them; to sponsor programs aimed at meeting these needs; and to encourage such engineering research as may be advisable in the national interest.

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Foreword

The National Academy of Engineering established the Aeronautics and Space Engineering Board (ASEB) in May 1967 to advise the National Aeronautics and Space Administration (NASA) and other government agencies. In consultation with officials of NASA, the Department of Transportation, the Federal Aviation Administration, the President's Science Adviser, certain interested committees of Congress, and the National Aeronautics and Space Council, as well as other government and private groups, the Board selected as its first topic of study, "Civil Aviation Research and Development: An Assessment of Federal Government Involvement." The Board's report under that title was published on August 13, 1968. It summarizes reports of six ad hoc committees, including this report by the Committee on Air Traffic Control.

As background information for the reader of the committee reports, the most important conclusions and recommendations of the Board are stated below (summary report, pages v-vi).

> The Board has concluded that in a favorable economic climate civil aviation can continue to flourish; in fact it can accelerate its beneficial growth if a carefully conceived program of planning and research and development aimed specifically at the civil air transport system is carried out.
>
> After considering the multiplicity of factors affecting the growth of civil aviation, the Board concluded that the three most critical factors are (1) airport and support facilities, (2) noise, and (3) air traffic control.
>
> The most important recommendation of the Board pertains to knitting together more tightly the civil aviation research and development activities of the Department of Transportation, its

activities of the Department of Transportation, its major operating unit, the Federal Aviation Administration, and the National Aeronautics and Space Administration, and especially to dividing their responsibilities according to capability. The DOT should provide the leadership in conducting systems studies to identify, analyze, and rank civil aviation goals as well as the research and development needed to attain these goals; NASA should be responsible for research and development in all the areas of importance to civil aeronautics; the FAA should, in addition to operating the airways network, be responsible for the systems testing of the resulting operational concepts and hardware.

The Committee on Air Traffic Control recommended that the DOT (FAA) should place major dependence for conduct of research and development on NASA, ESSA,* and industry, but did not include the further statement about responsibility for the research and development. It should be noted that the committee members were not unanimous in this recommendation. One member believed that DOT (FAA) should acquire the necessary additional funds and its own independent research and development capability. However, the parent Aeronautics and Space Engineering Board during consideration of all of the areas covered by the six ad hoc committees chose to make the recommendation in its summary report that NASA should be responsible for the research and development identified by DOT (FAA).

The Board's report also contained many detailed technical recommendations concerning research and development needed to ensure the continued growth of civil aviation. These pertain to most of the important areas of civil aviation, including systems and the specific areas of flight vehicles, aircraft operations, air traffic control, airport and support facilities, economics, and noise.

The Board assigned detailed work to six ad hoc committees covering the above specific areas. Each committee was composed of knowledgeable men from different parts of the aviation community; their valuable contributions are sincerely appreciated by the Board.

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*Environmental Science Services Administration.

Board membership is listed in Appendix I. The Board wishes to express its appreciation and indebtedness to a large number of individuals beyond its membership with whom it conferred. These are also listed in Appendix I. The Board is indebted to the American Institute of Aeronautics and Astronautics, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the Institute of Electrical and Electronics Engineers, and the Society of Automotive Engineers for conducting special studies, making available special reports, and identifying members for participation in an advisory capacity. The cooperation of these societies served to broaden the advisory base.

The Board is particularly grateful for the valuable assistance provided by the members of the Ad Hoc Committee on Air Traffic Control, who are listed on the following page.

AD HOC COMMITTEE ON

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Introduction

Organization for Conduct of the Air Traffic Control Study

Members of the Committee on Air Traffic Control were selected to bring into the study all aspects of each field of interest. The chairman and other members of the ASEB brought to the committee their experience in the fields of research and development, system management, and electronics system manufacturing. Advisers were included in the fields of system automation and flight control; navigation and communications research development, and system integration; and airline transport planning and operations. Other contributors brought consideration of the corporate and private (general aviation) sector into the discussions.

Method of Conducting the Study

In preparing this report, the committee chairman drew upon the advice and counsel of the members and advisers and on the suggestions offered by a number of other individuals in the traffic control systems field. Initially, these ideas, studies made by other groups in recent years, and the status of the present government and industry efforts in the air traffic field were reviewed. In addition to the information received from the professional engineering societies, the reports from other groups and organizations were very valuable during the study. Particularly valuable as background information were the statements of national aviation goals and recommendations made in the Project Horizon study and the recommendations made in the Project Beacon report. Both of these are discussed in the next section of the report, and they are related to progress made toward implementation in the years since their publication.

From the ideas presented by members and from studies available, a preliminary outline was prepared enumerating the major problems in the traffic control field. This outline was reviewed by the committee members. The committee then prepared a draft report. A final consideration by members and subsequent revision of the report were accomplished through consultation and correspondence.

Historical Summary of Previous Studies on Air Traffic Control

1. Federal Aviation Administration. A series of studies both in and out of government culminated in passage of the Federal Aviation Act of 1958, which created the Federal Aviation Agency. In 1966, the Department of Transportation Act provided that the Federal Aviation Agency would become a component of the Department of Transportation and be known as the Federal Aviation Administration.

The FAA's purpose as defined in the FAA Act of 1958 (and incorporated in the DOT Act of 1966) is included in the declaration of policy to guide the Administrator of the FAA in the performance of his powers and duties under the act. He is required, among other things, to consider as being in the public interest:

- The regulation of air commerce in such manner as to best promote its development and safety and fulfill the requirements of national defense
- The promotion, encouragement, and development of civil aeronautics
- The control of the use of the navigable airspace of the United States and the regulation of both civil and military operations in such airspace in the interest of safety and efficiency of both
- The consolidation of research and development with respect to air navigation facilities, as well as the installation and operation thereof
- The development and operation of a common system of air traffic control and navigation for both military and civil aircraft

Under these guides and as further authorized under the various titles of the act, the Administrator carries out numerous programs and activities.

The Federal Aviation Administration functions as a single organization. There are three basic levels of the organization with two special organizational complexes. The headquarters office provides for agencywide program planning, direction, control, and evaluation, and it conducts certain activities that can best be performed centrally. Regional offices direct operations in the field areas that are within assigned geographic boundaries. The FAA is responsible for safety regulation, for promulgation of regulations to include examination, inspection, certification (including medical), and rating of pilots and maintenance personnel, and for the administration of regulation and surveillance of regulated activities. The FAA provides for registration of aircraft and recordation of rights in aircraft. The FAA has the following functions and responsibilities for research and development: The organization develops, modifies, tests, and evaluates systems, procedures, facilities, and devices needed for safe and efficient navigation and traffic control of all civil and military aviation (except for certain needs of military agencies that are peculiar to air warfare and primarily of military concern). It defines the performance characteristics of systems, procedures, facilities, and devices, and it selects those that will best serve aviation needs and that will promote maximum coordination of air traffic control and the air defense system. It is also empowered to undertake or supervise developmental work and service testing to promote the development of improved aircraft, aircraft engines, propellers, and appliances.

The FAA is responsible for these activities:

- Establishment and operation of air navigation facilities
- Air space control and air traffic management
- Development of civil supersonic transport
- The Federal Aid to Airports Program (grants in aid for development of airports and promulgation of standards and for fostering the development of a national system of airports)
- Such programs as aviation war risk insurance and information manuals

2. <u>Summary of previous studies on air transportation and air traffic control.</u>

<u>Project Horizon.</u> This study of national aviation goals was directed by President Kennedy to Mr. N. E. Halaby,

FAA Administrator, on March 3, 1961. The Project Horizon study, under the chairmanship of Mr. Fred M. Glass, was completed and transmitted by Mr. Halaby to President Kennedy on September 5, 1961. National goals were identified and recommendations were made in the report aimed at establishing programs to accomplish the goals. A summary of the goals and recommendations is included in Appendix II.

Project Beacon. This study, directed by President Kennedy, was completed November 1, 1961 under the chairmanship of Mr. Richard R. Hough. Recommendation was made by Mr. Halaby to the President that the program outlined in the report be implemented. President Kennedy directed that implementation on November 7, 1961. Project Beacon generally provides an outline plan aimed at reaching the goals established under Project Horizon. A summary of problems identified and recommendations made in the Project Beacon report is included in Appendix II.

National Airspace Utilization System. This document is essentially the plan produced by the FAA in response to the directive to implement the recommendations of Project Beacon. The plan was published in June 1962. A brief description of the National Airspace System (NAS) En Route Stage A is included in Appendix II. This system, planned for implementation between 1967 and 1972, interfaces with the terminal controlled areas that vary from the most complex [such as New York, Chicago, or Los Angeles (Category V)] to the terminals with instrument-flight-rules capability but no control tower (Category II).

Although the FAA has produced revisions to the National Airspace Utilization System for internal use, no complete updating has been accomplished. Except for planning, programming, budgeting, and system documents produced as part of the regular FAA budget preparation, the system plan described above seems to be the "plan" for present and future operations of air traffic control.

3. Assessment of plan versus implementation. A reading of the recommendations in the Project Beacon report and a screening of present-day criticism of the air traffic control system operation would lead one to identify the following problems as still critical and unsolved:

a. There are mixed operations of instrument flight rules and visual flight rules en route and in terminal areas, with the terminal-area operations being most critical.

b. Communications capacity is not keeping pace with demand.

c. Pilots and controllers are frequently overloaded in high-use areas, en route and terminal.

d. Safety and efficiency are difficult to maintain, with safety achieved only through delay of traffic.

e. The present system of complicated departure and arrival patterns is a delaying factor in handling air traffic.

f. No satisfactory airborne collision warning system is available.

g. No satisfactory clear air turbulence warning system is available.

h. There is no satisfactory program for putting closer to real-time meteorological information into the air traffic system.

This sampling of commonly noted problems leads to the conclusion that the air traffic system is not keeping pace with the growth in air traffic, even today. The forecast by FAA* that United States air carrier enplanements will grow from 84.6 million in 1965 to 150.8 million by 1970 and to 258.0 million by 1975, in view of current delays experienced at several terminals, suggests the conclusion that the system capability will continue to fall behind the demand.

To further complicate the problem, the growth of general aviation is expected to be even greater than that of the commercial carriers. The FAA estimates that the general aviation fleet will grow from 95,000 aircraft in 1965 to over 172,000 aircraft in 1977.† Operations are expected to increase at an even greater rate, with the 13.7 million itinerant general aviation operations in 1965 estimated to grow to 55 million in 1977. With general aviation operations now receiving much of the blame for the congestion occurring in

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*Federal Aviation Administration, Aviation Forecasts, FY 67-77 revised to 1980 by the FAA Office of Policy Development, April 14, 1967.

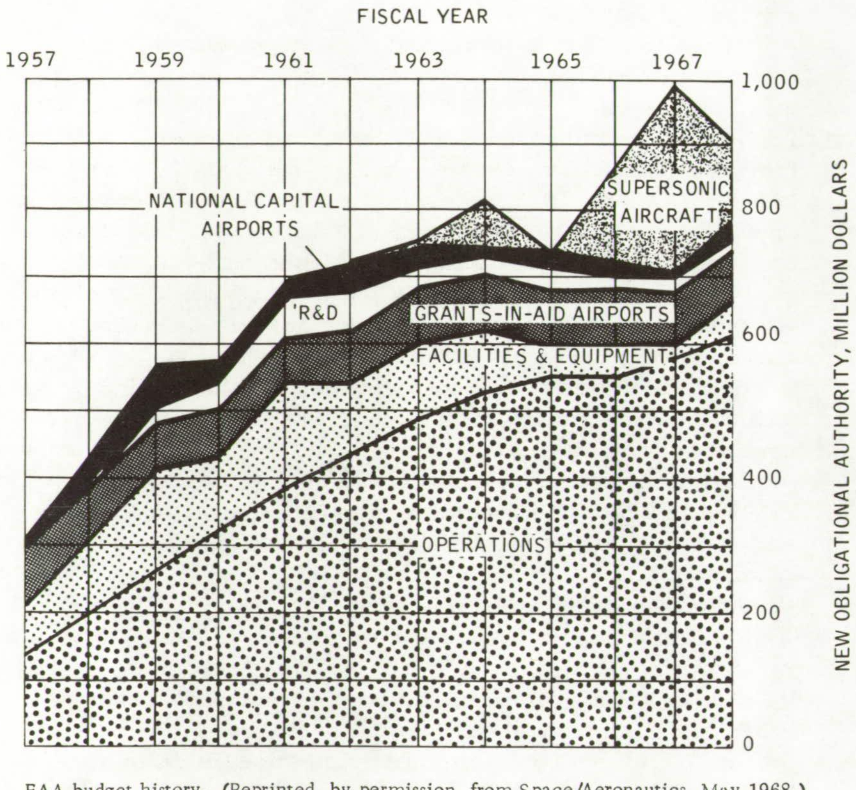
†Federal Aviation Administration, General Aviation: A Study and Forecast of the Fleet and Its Use in 1975, FAA Office of Policy Development, Economics Division, July 1966.

high-use areas, either restriction of general aviation or quantum improvement in traffic handling is indicated.

As a summary of progress made toward implementing the recommendations outlined in the Project Beacon report, two major points can be made.

First, the air traffic system has not kept pace with traffic demand, although the plan for national airspace utilization has made progress toward implementing the recommendations of the Project Beacon report. Implementation schedules for NAS have slipped substantially since 1962, and the recently amended schedules appear to be rather optimistic. The slipping of research and development and implementation schedules has resulted from expenditure and funding rates falling far below those originally planned (see Appendix II).

Figure 1

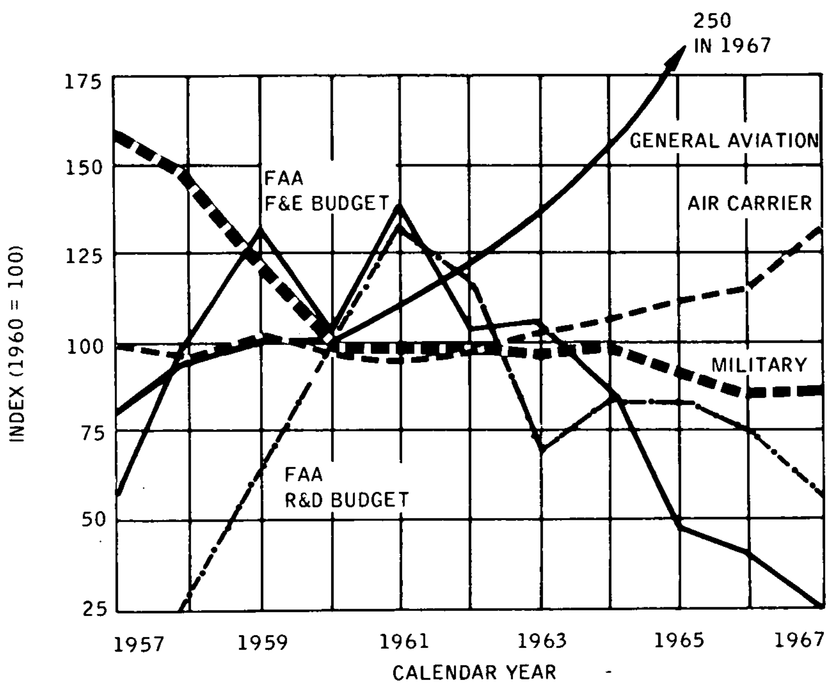


FAA budget history. (Reprinted, by permission, from Space/Aeronautics, May 1968.)

Second, a quantum improvement seems to be required soon if the traffic control system is to catch up and keep pace with air traffic growth.

Figures 1 and 2 illustrate the increasing urgency of the problem of congestion and suggest possible future safety problems. While operational demands on the system have been growing more rapidly than the operations budget, the squeeze has been severe on research and development and on funds for facilities and equipment.

Figure 2



Research and development and facilities budget trendlines normalized to 1960 base compared with FAA's own normalized trendlines for growth of aircraft operations, in three categories, at airports with FAA traffic-control service. (Reprinted, by permission, from Space/Aeronautics, May 1968.)

Scope of the Study

This survey of air traffic control problems and recommendations for necessary action is complementary to the surveys made by the other ASEB ad hoc committees. Ad hoc committees have considered the following topics:

Flight vehicles and airbreathing propulsion
Aircraft operations
Airport and support facilities
Economics of civil aviation
Noise

The Committee on Air Traffic Control considered the problems involved with regulation and control of civil air traffic in all phases: departure, en route, and in the terminal area.

This report points up a number of deficiencies in the air traffic control system as it now exists, along with recommendations for research and development required. In many cases, the committee has suggested agencies that it considered appropriate to carry out the recommended actions or to participate in such actions. In its summary report the Board generally chose to omit any such references, thus giving the agencies concerned the option of determining appropriate implementing activities. Many of the present deficiencies will undoubtedly be greatly lessened or eliminated by the introduction of system improvements now in late stages of development by the FAA. Because of time limitations the committee was unable to determine the extent to which the updated system will meet the requirements of the time period for which it is being designed. Such an assessment is of vital importance and should be made at an early date.

Discussion of Problems and Recommendations

CHARACTER OF AIR TRAFFIC CONTROL PROBLEMS

Sophisticated air traffic control (ATC) systems are now required and will be even more important in the future in solving the twin problems of safety and economic operation in an environment of extraordinary growth in volume and types of air traffic. Technological advances in airborne and ground-based equipment must be readily brought to bear on the problems, and governmental authority must be clarified to provide the integration necessary to the solution of ATC problems.

In this section, the component parts of the ATC problems are taken separately and characterized. First, the growth of air traffic – in volume and in type of aircraft – is described. Then, safety of civil aviation, the economics of traffic delays at terminals, a summary of aircraft ATC equipment technology, and the National Airspace System are discussed.

Growth of Air Traffic

Volume

The Federal Aviation Administration* has predicted that United States air carrier traffic will grow from 84.6 million enplanements in 1965 to 150.8 million by 1970 and to 258.0 million by 1975. General aviation growth is expected to be even greater. The FAA estimates* that the general aviation

*Federal Aviation Administration, Aviation Forecasts, FY 67-77 revised to 1980 by the FAA Office of Policy Development, April 14, 1967.

fleet will grow from 95,000 aircraft in 1965 to over 180,000 in 1977. During that time general aviation operations will increase from 13.7 million to 55 million itinerant flights. Military aircraft operations are expected to decline from 1.8 million flights in 1965 to 1.2 million in 1977.

Formerly, the great majority of general aviation flying was done under visual flight rules (VFR) and only entered the ATC system at airports served by a control tower. The trend over the most recent years, however, shows a greatly increased use of instrument flight rules (IFR) by general aviation aircraft. The number of IFR aircraft handled — that is, the total of contacts for departure, landing, and transfer of aircraft between ARTC centers – is one measure of IFR activity. General aviation aircraft handled in fiscal year (FY) 1963 were 0.9 million; in FY 1965, 1.3 million; and in FY 67, 2.2 million. The FAA estimates that the number of general aviation aircraft handled will be 5.4 million by FY 1972 and 14.7 million by FY 1979. The more than sixfold increase forecast between 1966 and 1979 compares with about a threefold increase forecast for similar operations by air carriers.

Types of Aircraft

Between 1957 and 1967 the number of free-world jet transport aircraft increased from zero to about 1,800; total passenger traffic increased from about 50 billion passenger miles a year to about 180 billion. By 1980 the jumbo jets and supersonic transports (SST) will make possible an increase up to 550 billion passenger miles a year. A free-world jet transport fleet of more than 4,700 aircraft is expected by 1970; of these, half will be long-range aircraft and half will be short- and medium-range aircraft.

Another type of aircraft that will impose requirements on the ATC system is the vertical and short takeoff and landing (V/STOL) aircraft. These aircraft are expected to increase markedly in numbers and scope of activity and thus in their use of the ATC system. Their unique capabilities will undoubtedly bring about an increase in the number of short commercial flights (less than 200 miles) around major terminals. The resulting diversity of departure and approach patterns interacting with other commercial and general aviation traffic will require that V/STOL aircraft be carefully considered in planning the future ATC system.

Major terminal airports will continue to handle various types of aircraft from V/STOL to the supersonic transport. At major terminals, passengers for the very large transports will be brought to the airport not only by ground transport but by air taxi, charter, short-haul, executive, and private general aviation aircraft. It is probably not economical or desirable to segregate such terminals by category of aircraft. However, the total system of approach procedures, landing guidance, runways, taxiways, and gates must be designed to handle these multiple types with a minimum of mutual interference. Coordinated integration is needed rather than segregation.

However, apart from the categories of general aviation requiring access to major airports, either for business at the airport or for the purpose of making further air travel connections, there is another significant volume of traffic. For these aircraft needing access only to the general metropolitan area, and not to the airline terminals, there may need to be consideration for provision of separate airports in the vicinity of certain major hubs.

Unless a much improved air traffic control system is in operation in the time period when increasing numbers of general aviation aircraft, including these new and radically different vehicles, are introduced into service, the inefficiency and resulting economic loss will be unacceptably large. With proper planning, these new vehicles can operate to relieve the congestion rather than to compound the problem.

Safety

A comparison of United States domestic scheduled air transport operations accidents with those for automobiles, buses, and trains reveals first that airline safety has shown a steadily decreasing rate of fatalities per 100 million passenger miles flown, from about 1.3 to 0.38 or less over the last 18 years. (See Appendix II, Table 4.) None of the other transportation modes has shown such a clear trend. It can be seen that bus and train modes show a somewhat smaller fatality rate than air. However, automobile rates are nearly eight times those for air. Average figures for 1961-1965 are given in Table 1.

Table 1

Passenger Fatalities per 100 Million Passenger Miles*

Year	Automobiles and Taxis	Buses	Passenger Trains	Domestic Scheduled Airlines	General Aviation Aircraft
1961-1965, average	2.28	0.168	0.08	0.272	20.0

Source: FAA Statistical Handbook of Aviation, 1966.

*The fatalities per 100 million passenger miles were based on an estimated 2.08 passengers per general aviation aircraft.

Taking a closer look at the domestic air carrier accidents for 1965 where there were fatalities, Table 5 in Appendix II shows that six of the ten occurred en route or during approach to a landing through inadvertent contact with the terrain. It is in this area of errors in navigation and inability to maintain a safe altitude during descent that major improvement in accident safety may be realized. An analysis of the record of all jet transport fatal accidents since July 1958 reveals that about one half of these occurred between the time when the airliner left cruising altitude and when it touched down on the runway.* Of this one half, all accidents involved collision with the ground or water in an unintended manner. Several airliners hit mountains while descending or holding. Several failed to flare from high rates of descent. Several hit terrain short of the runway. Each of these occurrences could be classed as navigation accidents since the airplanes were not flying intended flight paths. Most of these accidents occurred when the airliners were being flown under VFR and under circumstances where available instrument procedures and instrument aids would normally have been expected to provide adequate terrain

*Capt. W. M. Moss, "Special Aspects of Jet Statistics - 1966." Presented at Flight Safety Foundation International Air Safety Seminar, Madrid, 1966.

clearance. Probably most of these accidents would not have occurred if the airlines had been under IFR. This analysis leads to the following questions:

1. Would the universal use of IFR at all times improve the airlines safety record?

2. Can navigation procedures and equipment be devised which can be universally used by airliners to improve the airlines accident record with respect to unintended ground contacts?

It is the belief of this committee that these questions can be answered affirmatively and that it is technically and operationally feasible to institute such procedures into airline operations. While the actual reduction to the overall fatality rate could be established only through some years of actual operation, the very excellent safety record achieved during operation completely under IFR control leads to the conclusion that many of the accidents of the types just discussed could be prevented if universal IFR procedures were adopted for all airline operations. If this premise is accepted, one can see then that the fatality rate for airline operations could be considerably reduced from the present average.

One other point of interest is the comparison of the safety record of domestic airline operations with that of operations in international and territorial passenger service (Appendix II, Table 6). The average passenger fatality rate per 100 million passenger miles flown from 1961 to 1965 is comparable to the domestic record cited in Table 1, above. However, when one considers distribution of airline jet landings, United States and international, and the respective number of jet landing accidents, it can be seen that international operations are potentially less safe than those within the United States. Consider the case of jet landing accidents where air navigation or air traffic control facilities are involved. Although only 38 percent of the world's jet aircraft landings occur outside of North America, they account for 77 percent of the world's landing accidents where navigational or air traffic control facilities are involved.* It would seem that even though the ATC system in the United

*Air Transportation 1975 and Beyond, Transportation Workshop, 1967, p. 269.

States is overloaded, it still has achieved a relatively much better safety record that that achieved in international operations.

The general aviation safety record reveals a quite different picture (Appendix II, Table 7). An indication of the relative safety of various transportation modes can be obtained by a comparison of fatalities per 100 million passenger miles, but that is certainly only one of several methods one might use. However, for the operator-passenger who both drives an automobile and flies or rides in aircraft with some frequency, the fatality rate offers a reasonable basis for comparison. In the period 1961 to 1965 there were more than eight times as many fatalities per 100 million passenger miles in general aviation travel than in automobile and taxi travel. A similar comparison shows over seventy times as many fatalities for general aviation as for domestic scheduled airline travel, per 100 million passenger miles (shown previously in Table 1).

Recent statistics from FAA records show reported near-miss incidents in flight for all civil aviation operations to be over 550 for 2 1/2 months in 1968. If the present trend continues, the annual rate will be over 2,600 incidents.

The frequency of general aviation accidents and fatalities and the frequency of reported near-misses are alarming when one considers the forecast for civil aviation growth in the coming years. Considering these statistics and the views of many individuals closely involved with air operations and safety, the committee has been persuaded that emphasis must be placed on improvement of civil aviation safety.

In summary, it can be seen that operations within the relatively more sophisticated and efficient ATC system in the United States compared to international operations illustrate the contribution that such a system makes to safety. Moreover, to extend the demonstrated safety of operations under IFR to all airline operations would significantly improve the overall airline safety record. The ultimate goal of completely automated positive control, monitored by flight crews thus relieved from many distractions, would be expected to improve the safety record even more. Finally, careful attention to improvement of regulation, traffic control, and operation of general aviation aircraft is clearly indicated to achieve the objective of a significant improvement in the safety of such operations.

Economic Operations

A major result of an adequate ATC system is efficient (and thus economic) use of aircraft. Two factors directly affecting economics of operations are delays at the terminals and inefficient use of airspace.

The number of aircraft in use today is such that any inefficiency, particularly in terminal areas, results immediately in costly delays in aircraft movements. For example, from FAA data on the rush period traffic (4:00-8:00 p.m.) at the 20 busiest airports in the United States with daily flights averaging from 673 at Philadelphia to 1,800 at Chicago's O'Hare International Airport, the average landing delay varied from 4 to 40 minutes. Individual delays range upward to two hours or more, in many cases causing incoming aircraft to divert to airports other than their intended destination. In the March 13, 1968 Congressional Record, Senator Jacob Javits quoted an estimate based on FAA delay figures that airlines and travelers involved incur costs of $100 million per year as a result of such delays. FAA estimates provided during the hearings of the Aviation Subcommittee of the Senate Commerce Committee indicated that airlines lost 150,000 hours a year waiting to take off and land. Passengers wasted 10 million man-hours a year as a result. These figures are far below 1968 estimates.

Table 2, compiled from figures supplied by the FAA, the airlines, and air traffic controllers, shows the average number of daily takeoffs and landings at the 20 busiest commercial airports and the average rush-hour time a plane wastes circling the field or waiting to take off. Figure 3 shows a projection of the average delays for all airline operations at J. F. Kennedy Airport based on United Airlines' experience.

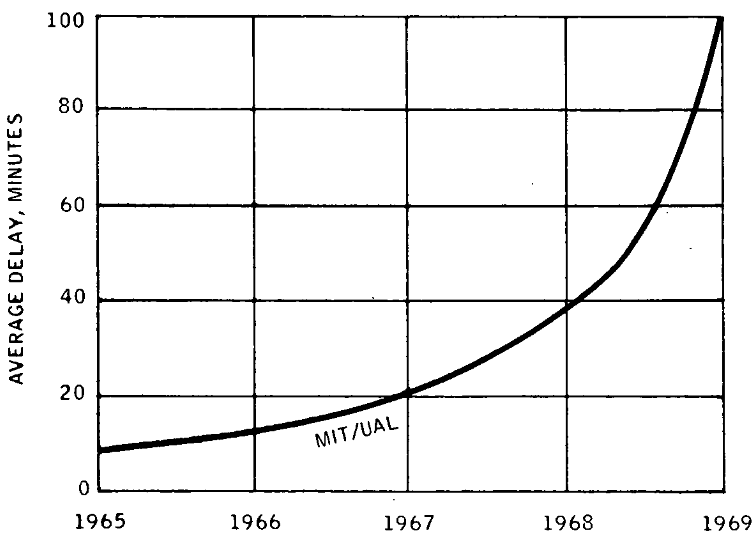
With regard to use of airspace, even today, there are many instances around the large hubs where required horizontal spacing and altitude separation cause departure or arrival delays. With the forecast of greatly increased numbers of commercial and general aviation aircraft in the next few years, there is a pressing need for careful analysis of the problem. Improved communications and airborne

Table 2

Rush-Hour Delays at Commercial Airports

Airport	Daily Flights	Delay In, minutes	Delay Out, minutes
Chicago O'Hare	1,800	10	16
New York Kennedy	1,537	20	40
Miami	1,209	7	12
Los Angeles	1,199	15	25
Denver	1,195	15	18
Dallas	945	9	11
St. Louis	937	4	5
Atlanta	905	12	15
Washington National	872	16	14
New York LaGuardia	866	15	35
San Francisco	819	11	15
Honolulu	799	5	6
Cleveland	797	5	6
Detroit	766	6	12
Minneapolis	753	5	10
Houston	737	5	11
Memphis	731	8	11
Baltimore Friendship	727	5	8
Newark	700	16	35
Philadelphia	673	10	15

Figure 3



Source: Report of Transportation Workshop, 1967. Attributed to R. W. Simpson, MIT and United Airlines, Operating Dependability in Air Transport, AIAA Paper No. 66-943, December 1966.

navigation and greater accuracy and capacity for the ground portion of an ATC system should allow expanded operation while still preventing delays.

Aircraft Equipment

In this section some areas are listed in which technological advances are needed in aircraft equipment.

General Aviation

As previously noted, the general aviation fleet continues to grow rapidly and is forecast by FAA to nearly double in the period 1965 to 1977. Operations are forecast to increase by a factor of 4 in the same period. In total numbers of aircraft and in total operations, general aviation is by far the largest segment of civil aviation and has specific additional need for effective and safe operations. It is expected that a large percentage of these general aviation aircraft will have IFR equipment and will be flown by IFR-rated pilots. Included in the fleet will be the small high-speed jet business aircraft, large jet and turboprop executive aircraft, and sophisticated piston engine aircraft capable of high-altitude IFR operations. Demands on pilots' capabilities will increase and needed reductions in pilot workload can be achieved by incorporation of:

1. Stability augmentation systems
2. Improved pilot visibility
3. Intruder detection systems
4. Better displays on very high frequency omnidirectional range, off-course navigation computers
5. Better communications

V/STOL Aircraft

It must be recognized that with the growth of two important public users of the lower airspace (V/STOL air transport and general aviation), a direct confrontation will undoubtedly develop in the technological areas. The use of common-system electronics may be essential to avoid having three electronic systems – one for aircraft using conventional takeoff and landing (CTOL) procedures, one for V/STOL air transports, and one for general aviation. Will the known technology of low-frequency navigation, secondary surveillance radar, low-visibility landing, communications, and data transmission permit an electronic-technological integration to evolve, or must electronically segregated systems emerge?

In answering this question, the obvious fact of sharing common airspace must be recognized. The ability to define the airspace more clearly and precisely is essential since this national resource is still abundant, if only the electronics and vehicle performance are matched to use as little as necessary in each case. Area navigation, centralized ATC, precision navigation systems, and overall air traffic surveillance on an optimized manual-automatic basis are related to the future of available V/STOL air transport systems as are the aeronautical designs.

A study is needed in the ATC area to define the problems clearly, to identify candidate electronic systems that can reasonably be considered, and to configure the V/STOL air carrier system of ATC so that it is compatible (if not common) with the general aviation and CTOL users of the airspace.

Also, emphasis must be given to the concepts of cooperative ground-airborne-space electronic systems and their interaction with self-contained airborne systems such as inertial and Doppler navigators, radio altimeters for landing, and collision avoidance systems.

A VTOL technological problem that must be overcome is its inherent instability during the transition and hovering phases. This problem involves flight dynamics and the avionics aids required for the proper matching of men and machines. Also, an accurate point-to-point navigation system using multiple flight paths under all weather conditions over densely populated regions is required, as is a highly reliable high-angle landing guidance system with an appropriate man-machine relation.

Commercial Air Transports

More precise flight control systems from takeoff through landing will be required to permit continued safety of operation with the predicted increase of traffic density.

Clear air turbulence is also a problem requiring advances in technology. A possible solution is real-time weather information incorporated in an ATC system or on-board equipment that would use sensors to detect turbulence 60 to 150 miles away. This problem is considered in greater detail by the Committee on Flight Vehicles and Air-breathing Propulsion and the Committee on Aircraft Operations, but its solution is paramount to efficient ATC system operation and the topic was also considered briefly by the Committee on Air Traffic Control.

Pilot-aircraft interrelationships must be looked at to determine the pilot role and need for automated equipment and displays. An entirely new display concept would provide (1) real-time display of all parameters for monitoring and aircraft management; and (2) an interchangeable graphic, alphanumeric, and symbolic display format to assist the pilot in maneuvering on the ground and in the air, including over the terminal area.

Some other areas in which equipment improvements are needed are:

1. Collision avoidance equipment – situation displays
2. Precision altimeter
3. Precision guidance and navigation equipment
4. Better communications
5. A complete system solution to the approach, landing guidance, and rollout problem – to include dynamics of flight, guidance, and human factors.

Studies should be made to determine whether today's technology could provide the above capabilities and, if so, what would be the increases in operational effectiveness. One approach to improvements for items 3 and 4 might be found through the multifunctional satellite.

National Airspace System

Improvements to the airspace element of the National Airspace System (NAS) are needed in the areas of efficiency and safety. These include overhaul of airway route structures and introduction of new airspace segment operating rules, coupled with reduction in airspace restrictions where feasible.

The Near-term Problem

The implementation of the National Airspace System has not proceeded as rapidly as planned and desired. There have been the general difficulties involved with implementing a system of the size and scope of the NAS; for example, delayed equipment deliveries and delays in assembling needed resources. Furthermore, the development and implementation problems have been underestimated, with the result that insufficient funding and inadequate technical resources have been applied in the past few years. It should be noted that probably a major factor for lack of funding was the pressure on the Bureau of the Budget and Congress for reduction to other than defense spending as a result of operations in Vietnam. The most serious consequence is that the program has been delayed substantially and is thus falling farther behind a rapidly advancing technology. Further compounding the difficulty is the fact that the air traffic control problem has changed in scope and character from that assumed for design of the system. There has been a more rapid increase in general aviation traffic, in incorporation of jet aircraft into operational use, and in total traffic than had been forecast. The single most important action with respect to the initial stage of the NAS is to speed its implementation so that the added operational capability can be realized as soon as possible. Research and development resources could then be brought to bear on the longer-range ATC problems. Near-term activities should be directed toward solving problems involved with the operational changeover from the existing system and to thorough testing of the elements of the NAS in order that needed improvements may be identified and quickly incorporated. These actions should be aimed particularly at achieving a further increase in capacity of the NAS. If the NAS is to be implemented on a timely schedule, then, as a matter of priority, attention should be given to increasing the funding and strengthening system management, system engineering, system production, system testing, and system evaluation.

In the interim period before full operation of the NAS is achieved, a number of areas within the current system need attention. Additional effort should be placed on improving present operational procedures and improving and upgrading existing ATC facilities. Effort is required to improve radar coverage, to achieve proper beacon utilization, to improve navigation and communication equipment, and to provide additional automation aids.

The Long-range Problem

Long-range improvements for the NAS navigation system will depend upon identification of NAS requirements not now known. Potential solutions to air navigation problems are inhibited by United States agreements through the International Civil Aviation Organization to protect the VORTAC system* for future time periods. Future United States requirements for capabilities beyond those now available for the NAS are not defined, but there are some reasons for considering replacement or modification of the current system with one that would avoid the present point-to-point route structures and permit parallel co-altitude airways with lateral separation standards below those already established. Future NAS navigation systems must consider complete replacement of the present VORTAC basic system by such alternatives as area navigation, use of satellites, integrated systems for communications, and navigation and airspace surveillance.

RECOMMENDATIONS

General Considerations

The volume of air traffic is already far greater in many en route and terminal areas than the present system can handle. Estimates for the future indicate that the deficiency will become progressively worse unless strong measures are taken to correct the imbalance between capability and traffic volume. During its study the committee became aware of problems that prevent the efficient application of government-industry-academic communities' talents toward providing an adequate air traffic system. There are areas where a more vigorous effort to apply existing technology will pay large dividends. There are certain areas where

*VHF omnidirectional range tactical air navigation system.

renewed emphasis on initiating needed research and development is clearly indicated.

In a number of instances, problems identified and recommendations made by previous study groups have not yet been implemented. The committee has included certain of these recommendations that appear still valid in the present traffic control environment. This has been done with the hope that progress can be made if the recommendations are brought once again to the attention of the agencies now responsible for implementation. Other recommendations made by the committee extend the scope to include long-range actions believed necessary to correct the traffic system deficiencies, and they cover measures aimed at accelerating incorporation of existing technology into the present ATC system, to accommodate new modes of air transport – such as the VTOL and STOL aircraft and the supersonic transports – that have been introduced into the national transportation system since the earlier studies or that are now in commercial production.

Government Responsibility and Authority

Safe, efficient use of the airspace--a national resource--is clearly one of the nation's air transportation goals. In order that the government-industry-academic capability and resources may be efficiently applied toward solution of the critical problems facing the air traffic system, clear delineation of government agency responsibilities and authority is required. In the nearly two years since the DOT was established, incorporating the FAA as an operating agency within the Department, there has been an opportunity for an assessment concerning effectiveness of the legislation. In the committee's view, assurance is needed that legislation, the National Airspace System plan, and long-range plans for the future traffic system needs are current and adequate. Without each of these elements operating in an effective fashion, timely incorporation of existing technology into the present system and initiation of research and development aimed at alleviating long-range problems will be hampered.

Recommendations:

1. Review the implementation of the FAA Act of 1958 and its relation to the DOT Act of 1966 to assure that the FAA has sufficient responsibility, talent, and authority (a) to plan for and regulate airspace; (b) to fund, design, construct, operate, and maintain the air traffic system; and (c) to accomplish or arrange through other agencies for accomplishment of the research and development necessary for long-range improvements to the air traffic system. The DOT should undertake this review.

2. Review previous documents, including the 1961 Project Horizon Study, the 1962 Project Beacon Study, the 1962 National Airspace Utilization Plan, and the "Policy Statement of the FAA," April 1965. Review and issue an updated National Airspace System plan that relates anticipated traffic to available technology and that provides for special attention to reducing the time required for incorporation of needed new technology. It is suggested that a full-time working group be convened for a sufficient period of time to study thoroughly and plan for the needed future program. The study should include careful consideration of the overall traffic control problem. The committee recommends the establishment of an adequate capability for system research and analysis and a capability for live system test and evaluation. It is recognized that costs are considerable for extensive analysis and live testing of a representative portion of the overall operational system. However, such expenditures at a timely phase of system implementation can reduce the far greater costs of retrofitting or redesigning a full system after installation. The FAA should undertake these tasks in cooperation with NASA, the Department of Defense, and the Department of Commerce (specifically, ESSA).

3. Review the regulations and concepts now in effect for the use of public airspace, and recommend changes required as a result of traffic growth.

Technology

The assessment of need for research, for development, and for the implementation of timely improvements in the air traffic system involves accurate forecasting of traffic growth and system capability, establishment of long-range requirements, and a testing and evaluation capability. To gain the necessary time for an orderly approach to quantum improvements needed in the air traffic system, the life span of the present system must be increased by rapid application of existing technology. Possible short-term measures include applied research efforts, engineering modifications, or analysis and incorporation of simplified and improved procedures.

Recommendations:

1. Refine forecasting techniques for application to traffic growth and define system capacity, for both air and ground by analysis, modeling simulation, and other approaches. Primary attention should be given to the terminal area. The FAA should undertake this task as a national program. With the ability to estimate traffic volume and to define system capacity accurately, an adequate analysis planning tool becomes available to study specific applications. The method of determining system capacity must be broad enough to encompass various types of flight and ground equipment as well as multiple runway arrangements. The FAA, in cooperation with NASA, should initiate required research and development and should implement the program.

2. Increase emphasis on the planning and initiation of needed research and development aimed at improvement in the air traffic system that will accommodate the quantum increase that is expected in air traffic. Within the total research and development effort, appropriate emphasis should be given to an ATC concept that places the maximum capability in the aircraft and minimizes the equipment and personnel required in the ground system. The following elements are involved in providing quantum improvements in the air traffic system:

Navigation. Establish and support research and development leading to high-precision en route and terminal navigation aids and equipment providing all-weather zero-zero operation. Emphasis should be placed on improved remote-area or over-ocean navigation (outside the range of line-of-sight navigation aids) allowing for spacing similar to that used in the domestic routes.

Communications. For the long-term solution of the ATC communications problem, introduce a program of increased research and development effort to accelerate development and use system analysis to select from the following alternatives or combinations thereof:

a. Ground-air-ground or a one-way air-ground data link

b. Automatic air-ground telemetering of additional vehicle data (i.e., heading, speed, altitude, and weather)

c. Integrated communications with navigation, surveillance, and possible hazard-avoidance signals

d. Satellite relays for communications, either as a single function or as a multiple function

Air Vehicles. Incorporate research and development with necessary live test and evaluation, to permit appropriate consideration of the various types of flight vehicles that will be in use (including helicopters, V/STOL aircraft, supersonic transports, and general aviation aircraft).

Weather. Establish a national program that includes supporting research and development efforts to provide closer to real-time integration of meteorological information into the air traffic system. Provide the system with severe-weather data, including forecasting of clear air turbulence, and those data required for safe and efficient operation of supersonic transports up to altitudes of 150,000 ft.

Airborne Collision Avoidance System. Continue and increase the emphasis on required research and development to provide for a system that will allow flight crews to recognize when they are on a collision course with other aircraft and that will indicate to crews in both aircraft the corrective actions open to them.

For these long-term improvement efforts, the DOT (FAA) should take the lead in setting requirements but should place major dependence for conduct of the research and development on NASA, the Department of Commerce (ESSA), and industry.

3. In order to provide the time for introducing the needed major improvement into the air traffic system, research and development and system evaluation should be emphasized to bring about evolutionary changes in the present National Airspace System En Route Stage A. Although no detailed analysis was made, the committee

members were convinced that increased attention should be given to the following:

Airspace Utilization. There are too many regulations. Most are out of date. Sensible, simplified designations, rules, and controls could solve present difficulties. Study and additional research and development where needed are recommended to:

a. Determine the need for and the extent to which positive control of airspace should be imposed; for high-density areas, require a transponder with altitude capability.

b. Permit scheduling of flights to allow for head-wind and tailwind problems, perhaps 10 to 15 percent below optimum speed. (Airlines would realize a saving by eliminating delays due to varying schedules and to jam-ups that now occur.)

c. Improve ground-based collision avoidance.

d. Develop and implement appropriate traffic segregation procedures.

e. Determine the impact and effectiveness of schedule control during peak periods in terminal areas.

f. Reduce pilots' and controllers' workload, and improve their working environment through simplification and automation of many of the functions now done manually.

Airports. The ASEB Committee on Airports and Support Facilities considered this area and made recommendations for solution of the problems identified. However, the en route and terminal traffic flow must be treated as integral parts of a system and it is becoming increasingly clear that major terminals need far more capacity than is now available. In its consideration of the overall traffic system the Committee on Air Traffic Control believed it appropriate to reemphasize need for greater effort on a number of the problems in the terminal area where a solution would pay large dividends. Additional study or research and development where needed are recommended to:

a. Improve flight procedures aimed at noise abatement. This step, however, should be considered only as an interim solution and any restrictions should be the minimum essential.

b. Eliminate existing obstructions around airports and prevent erection of additional obstructions that would restrict the use of new runways.

c. Increase airport capacities by establishment of parallel runways for simultaneous approaches using instrument landing system (ILS) procedures. Attention should be given to providing necessary high-speed runway exits.

d. Evaluate the need for addition of V/STOL facilities on existing airports to include capability for IFR operation.

Aeronautics and Space Engineering Board

Appendix I

Aeronautics and Space Engineering Board

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Background Data

Appendix II

Background Data

Project Horizon

Origin

1. The study was directed by President Kennedy to Mr. N.E. Halaby, FAA Administrator, on March 3, 1961.
2. The study was transmitted to Mr. Halaby by Mr. Fred M. Glass, Chairman of the Task Force on National Aviation Goals, on September 1, 1961.
3. The study was transmitted by Mr. Halaby to President Kennedy on September 5, 1961.

National Goals (excerpts)

1. Establish a comprehensive and viable program for development of a national aviation system that will make maximum contribution to:
   a. National economic growth
   b. National security
   c. National culture
   d. International commerce and trade
   e. World peace
2. Expand the appropriate utilization of aviation as an integral and indispensable part of our total national transportation system.
3. Attain and maintain an economically healthy, competitive, privately owned air carrier system capable of meeting the growing national needs of peacetime domestic and international air commerce, with the added capability in both equipment and organization of being immediately responsive to national military requirements in event of an emergency.
4. Accelerate the growth of general aviation, recognizing it as an essential and expanding element of the national air transportation system, enhancing both the business life and leisure time of those who use it.

5. Support and encourage the development of the civil cargo industry.

6. Develop and implement a single system for air traffic management that will ensure the safe and efficient use of our airspace by all operators – civil and military – and that is capable of growth and improvement in accordance with future traffic requirements and technological advances.

7. Achieve efficient and unified operation of such an air traffic system by establishing within the FAA a Federal Aviation Service that would operate the system in peacetime on a civilian basis, but that would become an integral part of the military services in time of national emergency or war.

8. Plan and implement a long-range nationwide system of airport and terminal development capable of keeping pace with the projected growth of air traffic and ensuring maximum safety and convenience to the public, maximum efficiency to all classes of air users, and maximum enhancement of the total economy of the nation and its individual communities.

9. Explore and fully exploit the contributions that the development of economic short-haul vehicles with V/STOL characteristics can make to our national transportation system.

10. Reduce the frequency and consequences of aviation accidents through systematic attention to principal causes and objectively derived corrective measures.

11. Reduce delays and dangers now caused by inclement weather through coordinated programs of research and implementation directed toward improving methods of forecasting weather, distributing weather information, and operating in inclement weather.

Report Recommendations

1. Terminals. All airports with a substantial volume of traffic, and properly located, should have instrument landing systems (ILS), runway lighting, and ATC towers. Airspace above existing and planned major airports should be "sky-zoned" in accordance with the latest safety criteria and traffic flow studies.

2. General Aviation

a. The FAA should expand its efforts to simplify, codify, and eliminate where feasible the regulations and rules under which general aviation operates. The FAA should also foster continuing research activities in testing, simplifying, and approving aviation systems and components used by general aviation.

b. The FAA should continue its air marking program,* retain the low-frequency radio ranges where they are more suitable than VORTAC, make the maximum practical airspace available for general aviation, and cooperate with state authorities in promoting and informing general aviation regarding safe operating procedures.

3. Safety

a. Steps must be taken by the FAA to ensure that users install and maintain the minimum airborne equipment needed to coordinate their safe and efficient flight with the national air traffic system.

b. Safety programs must be emphasized, expanded, and accelerated.

c. Research, development, testing, and experimentation on new navigational aids and new air traffic management systems, in addition to major improvements in other existing systems and services of significance to safety, must be stepped up.

d. Regulations must be improved, modified, and redesigned to reflect changing requirements.

e. Government educational programs in flight safety should be expanded as part of a general effort to upgrade the competence of pilots with minimum reliance on regulation and enforcement.

4. Research and Development. The work of the Bureau of Research and Development within the FAA should be reoriented in accordance with changing requirements and technology in ATC and related systems.

*Location markers placed on prominent buildings for visual position determination.

Project Beacon

Origin

1. The study was directed by President Kennedy to Mr. N. E. Halaby, FAA Administrator, on March 8, 1961.

2. The study was transmitted to Mr. Halaby by Mr. Richard R. Hough, Chairman of the Project Beacon Committee, on November 1, 1961.

3. The study was transmitted by Mr. Halaby to President Kennedy on November 7, 1961.

Air Traffic Problems

1. En Route System

a. The en route system is inefficient because of dependence on calculated position rather than on radar control.

b. The mixture of IFR and VFR traffic is most serious along the high-use airways.

c. There is a shortage of communications frequencies.

d. Both pilot and controller are overloaded in large degree because of position reporting.

2. Terminal System

a. Safety and efficiency are difficult to maintain. The problem is compounded at many inadequate and overloaded airports where safety is achieved only through delay of traffic.

b. The VFR-IFR mixture is most serious at terminals where climb and descent with inadequate altitude information complicate the controller's problems.

c. The present system of ground control and departure clearance delivery is cumbersome and inefficient. Terminals lack facilities to hold aircraft remote from the termination point and thus phase them smoothly into their approach.

d. The overall terminal system will be congested to the point of unacceptable delay and unsafe operation.

Short-Term Recommendations

1. In crowded terminal areas, segregate IFR and VFR traffic.

2. Require all landing aircraft at these high-density terminals to contact approach control at a specified (and remote) point away from the airport.

3. Implement airport improvement at once, where technology permits.

4. Expedite improved radar presentations.

5. Implement computer installation in the traffic system and provide data entry devices for controllers.

6. Automate receipt, handling, and issuance of flight plans.

7. Implement a program to incorporate high-visibility coatings and other results of research to improve in-flight visibility.

Recommended System

1. Base control of aircraft on information available on the ground.

2. In congested areas, segregate controlled and uncontrolled traffic and limit VFR speed.

3. Apply positive control normally to all traffic above 24,000 ft MSL near mountains, above 14,500 ft MSL elsewhere, and above 8,000 ft MSL in some high-density areas.

4. Establish controlled visual rules (CVR) for non-IFR pilots when visual reference is possible.

5. Limit speed below 8,000 ft MSL.

6. Require altitude-reporting beacons for aircraft 21,500 lb and above gross weight.

7. Combine SAGE/FAA radar nets and en route control.

8. In the terminal area, segregate aircraft by performance.

9. At controlled airports, require aircraft to contact the tower at a specified distance from the airport.

10. Require altitude-reporting transponders in all aircraft in terminal and other high-density areas. (A beacon for terminal use might soon be available for about $500.)

11. Provide special VFR corridors around congested areas.

12. Reduce pilot-controller communication. (This can be done if ground control position information is available.)

13. Use general-purpose computers for processing flight plans, issuing clearances, making conflict probes,

generating display information, establishing landing sequence, and performing routine tasks.

14. Establish special express routes in terminal areas.

NOTE: The task force estimated that five years would be needed to implement these recommendations. The necessary capital expenditure was estimated at $500 million, with an annual research and development budget of $65 million.

The following are suggested as needed improvements in the ATC system:

- Coordinate military needs through close cooperation of DOD-FAA.
- Concentrate on airport improvements to reduce congestion.
- Improve navigation means.
- Work toward all-weather landing.
- Work toward collision-avoidance and proximity warning system devices.

National Airspace System – En Route Stage A

What Is NAS?

1. General Description. NAS is an acronym for National Airspace System, which is a system of facilities, equipment, regulations, procedures, and personnel providing for the safe and efficient movement of aircraft through United States-controlled airspace. The Federal Aviation Administration is placing major emphasis on automation of the existing ATC subsystem, which, when implemented as now planned, will make automated ATC services available from takeoff to landing, whenever such services are warranted.

2. En Route Automation – NAS En Route Stage A

a. Evolutionary Approach. In order to avoid disrupting services presently provided or derogating safety, implementation of the automated ATC subsystem is being accomplished in well-planned evolutionary steps. The first of these steps is called "NAS En Route Stage A," which is designed to automate air route traffic control centers (ARTCC's).

b. Objectives. The broad objective of NAS En Route Stage A is to increase traffic-handling capability, to improve on an already strong safety record, and to promote better and faster service to air travelers by providing:

(1) Automation features for easy transfer and accurate processing and updating of flight information
(2) Automation aids for establishing and maintaining radar identification of aircraft in the system
(3) Automatic display of altitude or flight-level information with aircraft position
(4) A computer-processing capability to serve as the basis for future addition of automation improvements in ATC

c. Implementation. The implementation of NAS En Route Stage A will be accomplished in two phases.

Phase 1 -- Flight Data Processing. As a first step toward accomplishment of full Stage A operation, IBM 9020 computers and computer updating equipment manufactured by the Raytheon Corporation will be installed at all centers. ARTCC's will thereby be provided with a flight data processing (FDP) system that will provide an automation capability to (1) accept and store aircraft flight plans, (2) print and distribute flight plan information, (3) calculate and update flight data, and (4) transfer these data both within the facility and to adjacent facilities.

Phase 2 - Alphanumeric Display System. In the second phase, radar digitizers will be installed at long-range radar sites so that data will be brought into the center primarily by landline rather than by the present microwave system. The digitizers, known as common digitizers since they will be used by FAA and DOD, are being manufactured by the Burroughs Corporation. New Raytheon Corporation computer display channel components will replace existing Radar Bright Display Equipment. The digitized radar display system will provide aircraft data on the controller's display in alphanumerics. To accomplish this, the FDP computer program will be expanded. Thus a greater degree of automation will be provided for the en route facilities. This second phase of NAS Stage A will provide (1) automatic aircraft tracking, (2) visual flight information displayed upon the controller's radar scopes, and (3) automatic radar handoff capabilities.

3. System Interfaces. The various portions of the NAS ATC subsystem will provide automation for every facility (terminal and en route) where automation is warranted. Each of these facilities will be connected with adjacent facilities where appropriate:

a. NAS FDP centers
b. NAS Stage A centers
c. Manual centers
d. TRACON facilities
e. Flight service stations
f. Tower cabs
g. Airline operations
h. Military operations
i. National weather system
j. Air defense system

These will operate in combination as a national automated traffic control system.

4. The Role of the NAS Program Office. The focal point for implementation of NAS Stage A is the National Airspace Program Office (NASPO) in Washington. NASPO provides a single unified management responsible for coordinating the development, planning, and acquisition of an ATC system capable of meeting the expanding needs of the aviation community.

Why Do We Need NAS Stage A?

This question can perhaps best be answered by listing four basic reasons that will be expanded in the following paragraphs:

Increased traffic	Expanded service
Improved safety	Modernization

1. Increased Traffic. The marked increases in air traffic operations that have occurred within the last few years (and there are indications that it will double by 1972) point to the urgent need for a fast, dependable system for flight plan and radar data processing. Several ideas within ATC operations can benefit from automation that will:

a. Provide automatic data processing (ADP) of clerical and routine duties not involving decision making.

b. Minimize necessary controller-to-controller and controller-to-pilot coordination by providing needed information automatically.

c. Provide controllers with a complete display of their total air traffic picture.

d. Recognize situations created by human errors or equipment failures which may create potential problems for the controller or pilot.

e. Assist the controller in solving problems such as en route traffic flow congestion.

2. Improved Safety. This is the prime consideration not only for NAS but also for the FAA. All other aspects of agency service are secondary to aviation safety. The entire aviation community can be justly proud of its past safety record, but this is frequently purchased with costly delay. With the tremendous increase in aircraft volume and performance, the FAA cannot depend even on delay for safety. We must continuously implement new control procedures, utilize more sophisticated equipment, and retain manpower to ensure that the present record may not only be maintained but improved.

3. Expanded Service. Providing required services to the public is of major concern to the FAA. As an aviation-oriented agency, the FAA must provide essential services to the airspace users – general, air carrier, and military – in the most efficient manner possible. With NAS ATC subsystem implementation, the following benefits will accrue to the entire aviation community:

a. A significant decrease in pilot-controller communication contacts will allow both parties to devote more time to other critical tasks. It will also relieve frequency congestion and allow pilots to make necessary radio contact with a minimum of delay.

b. The automated FDP system will provide for the pilot's flight plans to be processed automatically, reducing costly delays due to heavy processing workloads at ARTCC's.

c. From all aircraft equipped with an automatic altitude-reporting transponder, the controller will continuously be provided with aircraft altitude information, virtually eliminating this chore from the pilot's workload.

d. The altitude information from equipped aircraft will simplify traffic advisories and will reduce frequency congestion.

e. The altitude transponder will allow each flight to be assigned a discrete beacon code, thereby providing a means for the controller to keep the aircraft in positive identification at all times.

f. The weather subsystem integrated to the overall system will feed precipitation contour information to controller displays, enabling the controller to advise pilots immediately of these conditions and suggest alternative courses.

4. Modernization. To provide better utilization of our limited airspace with the continuous introduction of faster, larger, and higher-flying aircraft, the FAA must provide continued improvement in terms of men, machinery, and systems.

When and Where Will NAS Be Implemented?

The NAS En Route Stage A program will affect every domestic ARTCC. TRACONS, flight service stations, base operations, and other facilities will also be provided with automation equipment. Implementation of NAS Stage A phase 1 has already been started in the Jacksonville, Florida, ARTCC. An IBM 9020 computer has been installed at the Cleveland ARTCC. Implementation of the remainder of the NAS program has been scheduled over a period of time to allow orderly transition from the present system to the automated system. Because of the magnitude of the task, it is difficult to pinpoint schedules at this time. However, the tasks involved with system implementation started in 1967 and will continue through 1972. Implementation is divided into two general categories with implementation of the first FDP system already underway. The program will continue through June 1970. Phase 2 of the NAS En Route Stage A program has also been started at Jacksonville, and system-wide implementation will continue through 1972. Current information on specific geographical locations and their proposed initial operational capability (IOC) dates is furnished and updated by the NASPO as changes are required.

Table 1

FAA PROGRAMS

		1966	1967	1968	FY 1969 $ in Millions
Operations Budget					
Air Traffic Control System					$ 295
Installation and Maintenance Services, Oklahoma City Depot, etc.					80
Maintenance Air Traffic Control System					162
Administration - Federal Standards Licensing, Certification, etc.					97
Research Division (administration)					11
Airports (operations not including Dulles and National)					13
Medical Program					5
					663
Facilities and Equipment					70
Federal Aid to Airports Program (FAAP)			$ 71	$ 66	70 (request)
SST Program	NOA		280	142	223
	EXP		145	100	351
National Capital Airports Operations (Dulles and National)			8.5	8.7	9.0 (request)
Airports - research and development		0.4	0.4	0.4	0.2
Research and Development					28
TOTAL, FY 1969, of Above Line Items					$1,063.2

Note: NOA - New Obligational Authority.
EXP - Expenditures.

Table 2

RESEARCH AND DEVELOPMENT

Applied Research, Technology, Test and Evaluation - $ in Millions												
FY	58	59	60	61	62	63	64	65	66	67	68	69
New Obligational Authority	20	30	49	65	60	35	40	40	38	28	28	28
Expenditures										36	33.5	29

Includes: Air Traffic Control) Navigation) See $ figures following. Weather)

Medical R&D) Aircraft Development) $ figures included in above but not available in detailed breakout. Difference in totals is due to difference between NOA and expenditures.

NOTE: No basic research is done by FAA.

Table 3

RESEARCH AND DEVELOPMENT BY MAJOR AREA OF RESPONSIBILITY AND TYPE OF ACTIVITY

	$ in Millions			
	FY 66	FY 67	FY 68	FY 69
AIR TRAFFIC CONTROL				
In-service Improvements	2.8	2.9	1.1	1.2
System Modernization	12.4	15.7	21.8	20.3
Long-range Studies and Analysis-Development	2.0	3.3	1.4	2.0
TOTAL	17.2	21.9	24.3	23.5
NAVIGATION				
In-service Improvements	0.9	1.8	1.6	2.0
System Modernization	5.0	3.5	2.9	3.5
Long-range Studies and Analysis-Development	0.7	0.5	0.3	0.4
TOTAL	7.6	5.8	4.8	5.9
WEATHER (FAA)				
In-service Improvements	0.1	0.1	<0.1	<0.1
System Modernization	1.2	1.2	<0.4	<0.7
Long-range Studies and Analysis-Development	0.2	0.2	<0.1	<0.1
TOTAL	1.5	1.5	>0.4	>0.8
GRAND TOTAL	$29.3	$29.2	$29.5	$30.2

Note: The above totals differ from the previous listing of new obligational authority and/or expenditures. Part of the difference results from the fact that Medical R&D and Aircraft Development are not shown above, and part because above figures are actual obligations, not NOA or expenditures. Figures were not available to show an entirely consistent picture, but the differences are not large.

Table 4

COMPARATIVE ACCIDENT DATA: 1948-1965

(Passenger fatalities per 100,000,000 passenger-miles)

Year	Passenger automobiles and taxis	Buses	Railroad passenger trains	Domestic scheduled air transport planes
1948	2.10	0.18	0.13	1.33
1949	2.70	0.20	0.08	1.32
1950	2.90	0.18	0.58	1.15
1951	3.00	0.24	0.43	1.30
1952	3.00	0.21	0.04	0.35
1953	2.90	0.18	0.16	0.56
1954	2.70	0.11	0.08	0.09
1955	2.70	0.18	0.07	0.76
1956	2.70	0.16	0.20	0.62
1957	2.60	0.19	0.07	0.12
1958	2.30	0.17	0.27	0.43
1959	2.30	0.21	0.05	0.69
1960	2.20	0.13	0.16	0.93
1961	2.10	0.19	0.10	0.38
1962	2.20 [a]	0.11	0.14	0.34
1963	2.30	0.23	0.07	0.12
1964	2.40	0.15	0.05	0.14
1965	2.40	0.16	0.06	0.38

[a] Revised.

Source: Motor vehicle data (automobiles, taxis, and buses) from the National Safety Council "Accident Facts" based on data from state traffic authorities, Bureau of Public Roads, National Association of Motor Bus Operators, and the Transportation Association of America. Railroad data from the National Safety Council "Accident Facts" based on data from the Interstate Commerce Commission. Domestic scheduled air transport data from CAB.

Table 5

FATAL AIRCRAFT ACCIDENTS IN U.S. AIR CARRIER OPERATIONS: 1965[a]

Date	Location	Operator	Type of Service	Aircraft	Damage	Fatalities				Total Aboard	Type of Accident
						Passg.	Crew	Other	Total		
Total all carriers						226	35	0	261	422	
Certificated route carriers						226	30	0	256	417	
2/ 8/65	Atlantic Ocean near Kennedy International	EAL	Passg. (S-D)	DC-7B	Dest.	79	5	--	84	84	Crashed shortly after takeoff.
8/16/65	Lake Michigan near Chicago, Ill.	UAL	Passg. (S-D)	B-727	Dest.	24	6	--	30	30	Crashed during descent for landing.
9/ 4/65	Lake Tustumena, Alaska	COA	Passg. (S-D)	Aero-Comm-60.	Dest.	3	1	--	4	5	Collided with water during flight.
9/17/65	Montserrat Island, British West Indies	PAWA	Passg. (S-I)	B-707	Dest.	21	9	--	30	30	Crashed en route.
11/ 8/65	Near Cincinnati, Ohio	AAL	Passg. (S-D)	B-727	Dest.	53	5	--	58	62	Crashed during approach for landing.
11/11/65	Salt Lake City, Utah	UAL	Passg. (S-D)	B-727	Dest.	43	0	--	43	91	Crashed on runway during landing.
12/ 4/65	North Salem, N.Y.	EAL	Passg. (S-D)	L-1049	Dest.	3	1	--	4	54	Midair collision.
		TWA	Passg. (S-D)	B-707	Subst.	--	--	--	0	58	
12/15/65	Northeast of Alamosa, Colo.	FTLX	Cargo (S-D)	L-1049H	Dest.	--	3	--	3	3	Crashed en route.
Supplemental carriers											
4/23/65	Mount Rainier, Wash.	AAXICO	Cargo (D)	DC-6A	Dest.	0	5	0	5	5	Crashed on mountain en route.

[a]Preliminary.

Source: Adapted from Bureau of Safety, CAB, Statistical Handbook of Aviation, FAA, 1966.

Table 6

AIRCRAFT ACCIDENTS, FATALITIES, AND FATALITY RATES — U.S. CERTIFICATED ROUTE AIR CARRIER SCHEDULED INTERNATIONAL/TERRITORIAL PASSENGER SERVICE: 1951-1965

Year	Aircraft Accidents		Fatalities			Passengers carried	Passenger miles flown (000)	Passenger fatality rate per 100 million passenger miles flown
	Total	Fatal	Total	Passenger	Crew			
1951.....	10	1	40	31	9	2,041,833	2,734,846	1.13
1952.....	9	3	103	94	9	2,366,451	3,176,784	2.95
1953.....	5	2	2	2	0	2,702,678	3,565,420	0.05
1954.....	4	0	0	0	0	2,878,800	3,904,459	0
1955.....	5	1	4	2	2	3,416,652	4,601,273	0.04
1956.....	1	0	0	0	0	3,950,671	5,307,543	0
1957.....	7	1	44	36	8	4,147,937	5,981,841	0.60
1958.....	12	2	10	10	0	4,272,340	6,230,732	0.16
1959.....	6	1	68	59	9	4,999,876	7,330,114	0.80
1960.....	5	2[a]	15	10	5	5,494,858	8,633,155	0.11
1961.....	2	0	0	0	0	5,699,421	9,153,562	0
1962.....	8	0	0	0	0	6,598,451	10,556,214	0
1963.....	10	1	81	73	8	7,513,251	12,439,917	0.59
1964.....	7	3	106	94	12	8,774,537	14,977,745	0.63
1965 (preliminary)..	8	1	30	21	9	10,195,430	17,541,783	0.12

[a] Midair collision, nonfatal to air-carrier occupants.

Note: Effective 1959, all States-Alaska operations of the Alaskan Air Carriers are carried as International/Territorial operations.

Source: Adapted from Bureau of Safety, CAB, Statistical Handbook of Aviation, FAA, 1966.

Table 7

AIRCRAFT ACCIDENTS, FATALITIES, AND ACCIDENT RATES — U.S. GENERAL AVIATION FLYING: 1951-1965

Year	Accidents		Fatalities	Estimated hours flown (000)[a]	Estimated plane-miles flown (000)[a]	Accident rates			
						100,000 hours		Million plane-miles	
	Total	Fatal				Total	Fatal	Total	Fatal
1951.	3,824	441	750	8,451	975,480	45.2	5.2	3.9	0.45
1952.	3,657	401	691	8,186	972,055	44.6	4.8	3.7	0.41
1953.	3,232	387	635	8,527	1,045,346	37.9	4.5	3.0	0.37
1954.	3,381	393	684	8,963	1,119,295	37.7	4.3	3.0	0.35
1955[b]	3,343	384	619	9,500	1,216,000	35.1	4.0	2.7	0.32
1956[b]	3,474	356	669	10,200	1,315,000	34.0	3.4	2.6	0.27
1957.	4,200	438	800	10,938	1,426,285	38.4	4.0	2.9	0.31
1958[b]	4,584	384	717	12,579	1,660,109	36.4	3.1	2.8	0.23
1959[b]	4,576	450	823	12,903	1,716,019	35.5	3.5	2.7	0.26
1960[b]	4,793	429	787	13,121	1,768,704	36.5	3.3	2.7	0.24
1961[b]	4,625	426	761	13,602	1,857,946	34.0	3.1	2.5	0.23
1962[c]	4,840	430	857	14,500	1,964,586	33.4	3.0	2.5	0.22
1963[b]	4,690	482	893	15,106	2,048,574	31.0	3.2	2.3	0.24
1964.	5,070	504	1,056	15,738	2,180,818	32.2	3.2	2.3	0.23
1965 (pre-liminary) .	5,250	516	1,018	16,733	2,562,380	31.4	3.1	2.0	0.20

[a]Estimated by FAA.

[b]No general aviation survey was conducted for the designated years. Estimated hours flown and estimated plane-miles flown for 1958-1961 have been revised according to correction factor based on the 1962 survey of aircraft use in general aviation. Data for 1963 are based on hours and use reported on aircraft inspection reports adjusted by the same correction factor.

[c]The 1962 general aviation survey excluded gliders, dirigibles, and ballons. These data have been adjusted to include them.

Source: Adapted from Bureau of Safety, CAB, Statistical Handbook of Aviation, FAA, 1966.

Bibliography

Appendix III

Bibliography

A. Air Traffic Control

1. "Aeronautics Research and Development," Dr. Robert C. Duncan, NASA Electronics Research Center, Cambridge, Mass., September 20, 1967.

2. "Air Traffic, Out of Control," Part I, a staff report. "Air Traffic, the Clearing Skies," Part II, a staff report. Flying, January 1968.

3. Project Horizon, a report by the Federal Aviation Agency, September 1961.

4. Project Beacon, a report of the Task Force on Air Traffic Control, by the Federal Aviation Agency, October 1961.

5. Design for the National Airspace Utilization System, a report by the Federal Aviation Agency, June 1962.

6. "Report of the Panel on Transportation Research and Development of the Commerce Technical Advisory Board," U.S. Department of Commerce, May 1965, PB 167186.

7. "Long Range Planning for the Air Traffic System," Radio Technical Commission for Aeronautics, March 17, 1967, DO-135.

8. "Air Transportation 1975 and Beyond, A Systems Approach," report of the Transportation Workshop, Bernard A. Schriever and William W. Seifert, co-chairmen, MIT Press, 1967.

B. General

1. "Some Views on Civil Aeronautical Research and Development," a special AIAA report consisting of working papers developed for the use of the ASEB, February 1, 1968.

2. "The Jumbo Jet and Public Safety," Jerome Lederer, Journal of the Royal Aeronautical Society, April 1968.

3. "Global Air Transport Accident Statistics," A. M. Lester, ICAO Bulletin, January 1967.

4. "Unresolved Civil Aeronautics Problems," Walter Tye, Journal of the Aerospace Sciences.

5. FAA Air Traffic Activity, Calendar Year 1967, published by the Department of Transportation, Federal Aviation Administration, February 1968.

6. "How the Airplane Designer Can Help the People in the Cockpit," George S. Schairer, presented to the Society of Automotive Engineers, New York, April 26, 1967.

7. "Flight Safety in the New Jet Era," Norbert E. Rowe, Astronautics and Aeronautics, September 1966.

8. "Annual Review of U.S. General Aviation Accidents," National Transportation Safety Board, Department of Transportation, November 1967.

9. "How Safe is Air Travel?" Frank Leary, Space/Aeronautics, May 1968.

10. "Survival in the Air Age," a report by the President's Air Policy Commission, January 1, 1948.

11. "Long Range Planning for the Air Traffic System," Radio Technical Commission for Aeronautics, March 17, 1967, DO 135.

12. "The United States Supersonic Transport — A Progress Report," John M. Swihart, The Boeing Company, AIAA paper No. 67-750.

13. "Kelly Johnson on the Future," Technical Information Service, AIAA.

14. RTCA Annual Report, 1967.

15. RTCA - Air Traffic System - Current Air Traffic Control Problems and Recommended Improvement Program, June 1963, 54-63/DO 120.

16. "Policy Planning for Aeronautical Research and Development," a staff report by the Legislative Reference Service, Library of Congress, for the Senate Committee on Aeronautical and Space Sciences, May 19, 1966, Doc. No. 90.

17. "Aeronautical Research and Development Policy," hearings before the Senate Committee on Aeronautical and Space Sciences, January 25-26, February 27, 1967.

18. "Science, Technology, and Public Policy During the 89th Congress," a report of the Subcommittee on Science, Research, and Development of the House Committee on Science and Astronautics, 90th Congress, Serial G.

19. "Technology Assessment," a statement by Emilio Q. Daddario, Chairman of Subcommittee on Science, Research, and Development of the House Committee on Science and Astronautics, 90th Congress, Serial I.

20. Statistical Handbook of Aviation, FAA, 1966.

21. General Aviation, A Study and Forecast of the Fleet and Its Use in 1975, FAA, July 1966.

22. Aviation Forecasts, Fiscal Years 1967-1977, FAA, January 1967.

23. Aviation Demand and Airport Facility Requirement Forecasts for Large Air Transportation Hubs Through 1980, FAA, August 1967.

24. "Transportation Facts and Trends," Transportation Association of America, Fifth Edition, April 1968.

25. Air Transport Facts and Figures, 1967, Air Transport Association.

26. "Maintenance of an Adequate Airport System," hearings before the Aviation Subcommittee, Senate Committee on Commerce, 90th Congress, August 28-31, 1967.

27. The National Airport System, Interim Report, Aviation Subcommittee, Senate Committee on Commerce, January 23, 1967.

28. "Aeronautical Research and Development Policy," report of the Committee on Aeronautical and Space Sciences, United States Senate, January 31, 1968.